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A GROUP FACTOR IN IMMEDIATE MEMORY

BY
ANNE ANASTASI, Ph.D.

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ACKNOWLEDGMENTS

The writer is deeply indebted to Prof. H. E. Garrett of the Department of Psychology, Columbia University, whose constant guidance, unfailing interest, and cooperation in countless ways have made the present study possible. She wishes to express her gratitude to Dr. M. R. Schneck, through whose assistance the subjects were obtained, and to Prof. H. D. Marsh and Mr. J. G. Peatman, who administered the tests in their respective laboratory sections in experimental psychology at the College of the City of New York. For permission to use Barnard College students of psychology in the preliminary experimentation, as well as for helpful criticisms and suggestions, grateful acknowledgment is made to Prof. H. L. Hollingworth. Thanks are also extended to Dr. Howard Gray and Messrs. T. A. Jackson, Prescott Lecky, and G. M. Smith, the instructors of the various psychology classes at Barnard College and Columbia University Extension, who graciously consented to the use of their students in the preliminary experimentation.

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A Group Factor in Immediate Memory

CHAPTER I.

THE PROBLEM*

I. Purpose of the Present Investigation

The present study is an experimental attack upon a specific problem in the organization of mental traits. Recent discussions regarding the presence of a number of independent "group factors" in mental organization make experimental identification and isolation of such factors timely and desirable. It is with one of these proposed "group factors," namely memory, that the present investigation is concerned. This study undertakes to find an experimental answer to the question of the existence of a common factor through a number of memory tests and its relation to other factors. If such a memory factory is discovered, a battery of tests for measuring it will then be constructed and the efficiency with which this battery estimates the central factor determined.

II. Principles Underlying the Choice of Tests

One of two principles could logically be followed in the selection of memory tests to be used in such a study. On the one hand, we could select a random sampling of as many different types of memory tests as possible, including variations in modality, materials, method, and duration of delay. On the other hand, we could restrict the scope of the tests, and proceed to an intensive investigation of some one phase of memory ability. The method of selection finally adopted is intermediate between these two principles. Obviously, the first method only could lead to a conclusive answer to the question of a general memory factor. However, if there should be no factor as general as this, but only more restricted memory group factors, it would be impossible to identify such smaller factors unless a sufficiently large number of tests of each type had been used. If this were done, however, the number of necessary tests would be too large to use in a single study on a single group of subjects. On the other hand, if the study is restricted too narrowly, then whatever group factors are found will be too restricted to be of much significance. It was finally decided to limit the study to immediate memory for visually presented material. Within this field, variations of method and material were introduced. If the existence of a group factor of immediate memory is established in the present study, it will then be feasible to combine tests of immediate and delayed memory in a more comprehensive search for a group factor through all memory tests.

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* This study is one of a series of researches (under the general direction of Professor H. E. Garrett) supported by a grant from the Council for Research in the Social Sciences, Columbia University.

In the construction of the memory tests, the attempt was made to eliminate as far as possible the presence of variables other than memory, in order not to complicate the relationships found. Any procedure involving fine discriminations or very close or sustained attention was carefully excluded. The use of "logical" material was also considered undesirable, since its recall depends on too many variables other than memory, such as interest in and understanding of the passage used, information, past experience, etc.

In order to establish the independence of the memory factor, it is essential to include in the study a number of non-memory tests. For this purpose, three tests were selected which were as nearly as possible measures of three other group factors, *viz.*, verbal and numerical ability and a possible spatial ability. Although the presence of the last-named factor has not yet been established, the most carefully constructed "spatial" test available was used. The factors of verbal and numerical ability having already been investigated,[1] it was possible in these cases to use tests whose efficiency in measuring the central factor was definitely known.

III. Principles Underlying the Choice of Subjects

A special attempt has been made in the present study to obtain a high degree of homogeneity within the group of subjects used, in order to avoid spurious correlations resulting from extreme variations within the group. Heterogeneity may arise from differences in maturity, sex, racial or national descent, educational or social status, and similar influences of heredity or environment; such heterogeneity may either raise or lower a correlation coefficient, depending upon whether the two variables correlated vary in the same or opposite direction, respectively, as the third variable. A group heterogeneous with respect to maturity usually yields correlations higher than the true value, since most capacities increase with age. The two variables correlated, in this case, would always vary in the same direction with the third variable, age, both increasing as age increases. It is also possible, however, for heterogeneity to lower a correlation coefficient. Let us suppose that a sampling is made up of two groups, of, for example, different racial extraction. Now, if one of the two races excels the other markedly in trait A, but is decidedly inferior to it in trait B, then lumping the two groups would tend to produce a negative correlation between traits A and B, and would therefore yield a value lower than the relationship existing within either of the two groups.

---

[1] Cf. Schneck (34).

Having shown that heterogeneity does affect a correlation coefficient, it may be well to discuss just how far homogeneity in a sampling yields results which are the best approximation to the "true" relationships sought. If it were possible to obtain a group of subjects perfectly identical with respect to all influences of heredity and environment, there would be zero variability in all traits within the group and no correlation between any of the variables could be obtained. Obviously, we should not want to eliminate all heterogeneity, even if such a thing were possible. What we actually want to find in any study of trait organization are the relationships existing within the total population about which we draw conclusions, in most studies this population being the total human race. Now, if we select extreme groups and lump them together in treating the data, obviously the relationships found will not be those which we would find if we tested the entire human race. Since most abilities have been found to be distributed according to the normal Gaussian curve, extreme cases will be very few in the total population. Furthermore, the effect of a few extreme deviations on a correlation coefficient will be less, the larger the number of cases. It is obvious that, since $r = \frac{\Sigma xy}{N\sigma_x\sigma_y}$, the effect of any one product-deviation on r increases inversely as the size of N.[2] Therefore, if we wish to obtain the relationships existing in the total population, we must have fewer extreme deviations, *i.e.*, our group must be more homogeneous, the smaller the N. It is, of course, impossible to determine the exact degree of homogeneity required in the sampling to make the results representative. The safer policy therefore seems to be to err in the direction of excess rather than insufficient homogeneity, obtaining as a result correlations lower, rather than higher than the "true" relation. This may obscure a "true" relationship which is very small; however, the discovery of such a relationship, so small in the first place, would hardly be very valuable. This result certainly seems less seriously misleading than the spurious appearance of correlation where there is no "true" relationship.

The maturity factor was controlled in the present study by the use of adult subjects, all of whom were either past or very close to their growth limit in mental capacities. This was considered preferable to the use of children of the same chronological age. Until more definite information is available on growth curves, we cannot justifiably assume that all children of the same chronological age have attained the same proportion of their ultimate adult capacity. Hence, we cannot be certain that we have controlled the maturity factor by holding chronological age constant, unless all our subjects have reached or passed their mental growth limit.

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[2] An illustration will make this clearer: Using reduced scores, all σ's equal to 1, then $r = \frac{\Sigma z_1 z_2}{N}$

Let $\Sigma z_1 z_2 = k + 3$, in which 3 is *one* of the product-deviations
Let $\Sigma z'_1 z'_2 = k + 7$, in which 7 is *one* of the product-deviations

If N = 10,

$$r = \frac{\Sigma z_1 z_2}{10} = \frac{k}{10} + .3 = C + .3$$

$$r' = \frac{\Sigma z'_1 z'_2}{10} = \frac{k}{10} + .7 = C + .7$$

$\therefore$ the difference in r is .4

If N = 100,

$$r = \frac{\Sigma z_1 z_2}{100} = \frac{k}{100} + .03 = C + .03$$

$$r' = \frac{\Sigma z'_1 z'_2}{100} = \frac{k}{100} + .07 = C + .07$$

$\therefore$ the difference in r is .04

CHAPTER II.

THE LITERATURE

A survey of the experimental literature on memory in search of data bearing on the interrelationships of memory tests yields a number of miscellaneous correlation coefficients, frequently computed only incidentally to the solution of some other problem. In most studies, only a few of all the possible intercorrelations of the variables used have been computed; systematic correlation studies on memory are very rare; only two or three go beyond correlation and apply some more conclusive criterion in the attempt to arrive at a general memory factor. These latter studies will be discussed in greater detail further in the present chapter. In addition, an attempt has been made to present a systematic analysis of correlations which have been reported in the literature on memory. These include correlations among different tests of memory, as well as a few correlations between memory tests and tests or estimates of other capacities. The data have been analyzed and tabulated on the basis of the criteria considered most significant in the present approach to the problem. These criteria include: number and description of subjects, in an attempt to get at the statistical reliability of the results with regard to size of N and homogeneity of the sampling; a brief description of the tests used, with special reference to materials, modality, number of repetitions, duration of delay, and method of testing retention; finally, the reliability coefficients of the tests used whenever reported, and the intercorrelations computed are given. It is hoped that whatever value the present or similar investigations may derive from these past studies on memory, will be brought out more fully by this analysis of the data. This analysis is presented in Table I. The studies reported have been arranged in chronological order.

A few of the studies reported in Table I have been selected for more detailed discussion, as bearing more directly on the present problem in their general method of approach. Carey (Table I—No. 11) after obtaining the correlations of his pooled tests of visual, auditory, and verbal memory, with each other, computed the correlation of each pool with what was

TABLE I.

MISCELLANEOUS CORRELATIONS WITH MEMORY TESTS.

	Subjects					
Reference	*N*	*Description*	*Tests Used**	*Reliability Coefficient*	*Intercorrelations Computed†*	(N)
1. Wissler (49), 1901	86 to 144 (N reported next to each r in column VI)	Columbia College Freshmen and Seniors	1. Auditory memory for digits (correctly written)	Not reported	$r_{13} = .29$	(144)
			2. Auditory memory for digits (correctly placed)		$r_{15} = .05$	(94)
			3. Visual memory for digits (correctly written)		$r_{17} = .16$	(121)
			4. Visual memory for digits (correctly placed)		$r_{24} = .39$	(144)
			5. Auditory logical memory for a prose passage		$r_{25} = .04$	(94)
			6. Incidental memory: reproduction of a 5 cm. line		$r_{34} = -.07$	(91)
			7. College standing		$r_{57} = .19$	(86)
2. Henderson (21), 1903	12	Columbia University students in psychology	Visual logical memory, for prose passages, studied for three minutes.	Not reported	(Spearman rank-difference r) $r_{12} = .61$	
			Three Passages used: 1. Historical 2. Descriptive 3. Expository		$r_{13} = .85$ $r_{23} = .50$ (above r's are for immediate reprod.)	
			Each passage tested for: a. Immediate reproduction		Correlating % loss in 3rd reprod.: $r_{12} = -.25$	
			b. Reproduction after 2 day interval		$r_{13} = .54$	
			c. Reproduction after 4 week interval		$r_{23} = -.09$	

* All tests are of immediate memory, unless otherwise indicated.

† All correlation coefficients are computed by the Pearson product-moment formula, unless otherwise indicated.

TABLE I—CONTINUED.

	Subjects				
Reference	*N*	*Description*	*Tests Used**	*Reliability Coefficient*	*Intercorrelations Computed†*
3. Krueger and Spearman (29), 1906	11	Adults, trained in psychology	1. Addition 2. Sentence completion 3. Tone discrimination 4. "Sense of space" 5. Memory for lists of 6, 8, 10, and 12 digits	.76 ± .07 .75 ± .09 .87 ± .04 .42 ± .15 .92 ± .03	(Spearman rank-difference r) raw r's: $r_{15} = .14 \pm .20$ $r_{25} = -.07 \pm .25$ $r_{35} = .17 \pm .20$ $r_{45} = .13 \pm .19$
4. Brown (6), 1909	I—66 II—39 III—40 IV—56	Schoolboys (age 11-12) Schoolgirls (age 11-12) Schoolboys (age 11-12) Women, training college students	1. Visual memory for nonsense syllables (delayed reproduction—24 hours) 2. Visual memory for poetry (delayed reproduction — 24 hours)	I : .68 IV : .67 Not reported.	Correlations computed with a number of tests (sensory, associative, etc.) and with school marks and estimates of general intelligence. r's of (1) range from —.23 to +.59, for (2) from —.11 to +.60
5. Burt (7), 1909	43	Gr. I: 13 boys in elem. school lower middle class. Gr. II: 30 boys in prep. school, superior social status.	1. Memory for lists of concrete or abstract monosyllabic words or nonsense syllables, of 4 to 8 items (presentation visual, auditory, and spoken by subject, simultaneously) 2. Teacher's and companions' estimates of general intelligence	I : .70 II : .93	(Spearman Foot-rule R) $r_{12} = .57$ (Gr. I) $= .78$ (Gr. II)

TABLE I—CONTINUED.

Reference	*Subjects* *N*	*Description*	*Tests Used**	*Reliability Coefficient*	*Intercorrelations Computed†*
6. Winch (48), 1911	I : 28	Schoolboys, average age 13-4, all in Standard VII, from "rather poor neighborhood"	1. Three tests (a, b, c) of visual logical memory for a story	(Computed in Gr. I only) $\left.\begin{matrix} r_{ab} = .65 \\ r_{bc} = .68 \end{matrix}\right\}$ 1.	I: $r_{12} = .749 \pm .05$
	II : 55	Schoolgirls, average age 12-11, in Standard VI and VII from "poor neighborhood"	2. Five tests (a, b, c, d, e) of imagination, making up a story, including a given set of words in it	$\left.\begin{matrix} r_{ab} = .57 \\ r_{bc} = .48 \\ r_{cd} = .51 \\ r_{de} = .55 \end{matrix}\right\}$ 2.	II: $r_{12} = .55 \pm .09$
	III : 32	Schoolgirls, average age 13-6, in upper Standard V and Standards VI and VII, from "very poor neighborhood"			III: $r_{12} = .48 \pm .09$ $.43 \pm .10$
	IV : 36	Schoolgirls, average age 8-9, in Standard II, from same school as Gr. III			IV: $r_{12} = .276 \pm .10$
	V : 30	Schoolboys, average age 12-11, Standard VII, "good school"			V: $r_{12} = .623 \pm .07$

TABLE I—CONTINUED.

	Subjects				
Reference	N	Description	Tests Used*	Reliability Coefficient	Intercorrelations Computed†
7. Abelson (1), 1911	43 M. 88 F.	Children in 8 London County Schools for mental defectives	1. Auditory memory span for sentences 2. Auditory memory for series of names of objects 3. Auditory memory for a series of commissions 4. Other measures, including teachers' estimates of intelligence, as well as tests of association and sensory and motor capacities	.79 (M), .78 (F) .81 (M), .74 (F) .70 (M), .73 (F)	(Spearman Foot-Rule R, reduced to $r = \sin\left(\frac{\pi}{2}R\right)$ $r_{12} = .66 \pm .07$ M $.42 \pm .06$ F $r_{13} = .38 \pm .10$ M $.50 \pm .07$ F $r_{23} = .38 \pm .09$ M $.34 \pm .07$ F Correlation with pool of other tests, for test: (1), = .46 M .67 F (2), = .40 M .37 F (3), = .40 M .58 F
8. Simpson (35), 1912	I: 17 II : 20	Columbia University professors and advanced students Low grade unemployed men in missions	1. Memory for words (auditory) 2. Memory for a passage (auditory) 3. Recognition of forms (visual) Also other tests of association, discrimination, etc.	I II (1) .48 .49 (2) .78 .83 (3) .69 .91 Both (1) .73 (2) .90 (3) .90	I II Both $r_{12} = .23$ .73 .82 $r_{13} = .37$ .15 .71 $r_{23} = .14$ .06 .66 All correlations very high: some r's with non-memory tests even higher than the above

TABLE I—CONTINUED.

Reference	*Subjects* *N*	*Description*	*Tests Used**	*Reliability Coefficient*	*Intercorrelations Computed†*
9. Heymans and Brugmans (22), 1913	15	Adult students	Memory Tests: 1. Color recognition: comparison with a standard previously seen (interval 1 min. or 1 hr.) 2. Recognition of rate of metronome (same procedure as in (1)) 3. Visual memory for lists of ten nonsense syllables, 3 presentations 4. Description of pictures from memory (immediate, 1 hr. and 1 wk. interval) 5. Auditory logical memory for a story (interval 1 hr. and 1 wk.) 6. Comparison of pictures from memory. Also tests of imagination, perseveration, attention, and abstract thought.	Not reported	All intercorrelations computed. Intercorrelations of memory tests, average +.20, range —.37 to +.71 Correlations between combined scores of all tests of each function and combined memory tests. Imagination: +.75 Perseveration: —.29 Attention: +.73 Abstract thought: +.54
10. Wyatt, (51), 1913	34	English school children, both sexes, age 11 to 13, superior social status	1. Visual memory for lists of 10 nonsense syllables 2. Same as 1, after interval of 2 days 3. Visual memory for letter square of 12 consonants 4. Teacher's estimates of general intelligence	.76 Not reported .75 Not reported	$r_{14} = .59 \pm .07$ $r_{24} = .74 \pm .06$ $r_{34} = .18 \pm .11$

TABLE I—CONTINUED.

Reference	*Subjects*		*Tests Used**	*Reliability Coefficient*	*Intercorrelations Computed†*
	N	*Description*			
11. Carey (9), 1915	Total of "about 150." This N was made up of 5 classes, treated separately and results then averaged.	English school children, of both sexes, age 7 to 14	a. Verbal memory for unrelated words (3 presentations), 3 tests, each in a different modality: auditory, auditory-motor, and visual b. Verbal memory for associated words (3 presentations) c. Sensory memory: 3 auditory and 4 visual tests d. Logical memory for a story, auditory-motor (3 presentations) e. Paired associates, word-number, auditory-motor (3 presentations) Memory tests pooled into 3 groups: 1. Auditory memory 2. Visual memory 3. Verbal memory	Reliability coefficients of "pools": .68 .64 .81	All intercorrelations of the tests reported. Correlations of the 3 memory pools $r_{12} = .44 \pm .054$ $r_{13} = .33 \pm .058$ $r_{23} = .28 \pm .061$ (*cf.* discussion pg. 23 for further results)
12. Travis (42), 1915	128 69 M 59 F	Students at the University of Pennsylvania	Logical memory (auditory): 1. Passage from Binet scale 2. Passage from Stanford-Binet scale Also college grades	Not reported	No r computed, but all ranks given for each distribution. From this author concludes that there is no correlation between the 2 memory tests or between these and college grades.

TABLE I—CONTINUED.

Reference	*Subjects*		*Tests Used**	*Reliability Coefficient*	*Intercorrelations Computed†*
	N	*Description*			
13. Bell (4), 1916	Total of 730, smallest single group 129	University of Texas Freshmen.	1. Recognition of forms. 2. College grades. 3. Other laboratory tests (association, learning, etc.)	Not reported	Average $r_{12} = .12$ Average $r_{13} = .14$
14. Bennett (5), 1916	9	2 Professors, 4 graduate students, and 3 seniors at University of Wisconsin	Visual and auditory presentation of each material except memory for faces (visual only): 1. Memory span for digits 2. Memory span for syllables 3. Memory span for nouns 4. Memory for prose passages, descriptive, narrative, and expositive 5. Recognition of photographs. Each test scored by number of repetitions required to learn, and score in delayed recall.	Not reported	(Spearman rank-difference r) All intercorrelations computed range from —.78 to +.88 P.E.'s very high because of small N
15. Gates (15), 1916	197 63 M 134 F (r's computed separately for each sex)	College students	1. Auditory digit span 2. Visual digit span 3. Substitution code learning 4. Visual form recognition 5. Auditory logical memory	Not reported	(Spearman rank-difference r's). All intercorrelations given, range from +.07 to +.41, average +.23. Average r of each test with all others: (1) = .29 (2) = .22 (3) = .26 (4) = .22 (5) = .16

TABLE I—CONTINUED.

	Subjects				
Reference	*N*	*Description*	*Tests Used**	*Reliability Coefficient*	*Intercorrelations Computed*†
16. Gates (16), 1916	172 84 M 88 F	School children in grades VI to VIII (Separate correlations computed for each grade and sex)	1. Auditory memory for digits 2. Visual memory for digits 3. Visual nonsense syllable recognition	Not reported	(Spearman rank-difference r) $r_{12} = .57$ $r_{13} = .17$ $r_{23} = .11$
17. Waugh (45), 1916	123	Beloit College Freshmen	1. Memory for prose passage, auditory. (Score is ratio of number of ideas retained after two weeks to number reproduced immediately) 2. Class standing	Not reported	$r_{12} = .40$
18. Guillet (20), 1917	I : 82 II : 87	Young women in Normal School	Auditory presentation: all combinations of the following methods and materials: Methods: 1. Immediate, 1 presentation 2. Immediate, 2 spaced presentations 3. Delayed. 2 spaced presentations Materials: (1) Digits, (2) Nonsense-syllables, (3) Unrelated words, (4) Related words, (5) Continuous prose.	Not reported	17 intercorrelations of the variables, range —.29 to +.75, averaging +.34. Also 22 correlations of these tests with several school subjects, range —.09 to +.41, averaging .18.

TABLE I—CONTINUED.

Reference	*Subjects*		*Tests Used**	*Reliability Coefficient*	*Intercorrelations Computed†*
	N	*Description*			
19. Kitson (28), 1917	40 31 M 9 F	Freshmen, sophomores, and juniors in College of Commerce and Administration, University of Chicago	1. Auditory memory for digits 2. Auditory memory for prose (immediate) 3. Auditory memory for prose (delayed) 4. Visual memory for objects 5. Visual memory for prose (immediate) 6. Visual memory for prose (delayed)	Not reported	$r_{12} = -.09 \pm .10$ $r_{14} = .09 \pm .10$ $r_{23} = .49 \pm .08$ $r_{25} = .26 \pm .10$ $r_{36} = .54 \pm .07$ $r_{45} = -.13 \pm .10$ $r_{56} = .45 \pm .08$
20. Gates (17), 1918	Total of 318, in groups of 37 to 43	School children in grades III to VIII. (Correlations computed separately for each group and then averaged	1. Immediate memory for nonsense syllables 2. Immediate memory for prose passage 3. Delayed memory for nonsense syllables 4. Delayed memory for prose passage (All memory tests visual) 5. Teachers' estimates of intelligence	Not reported	$r_{13} = .70 \pm .04$ $r_{24} = .82 \pm .04$ $r_{15} = .43$ $r_{25} = .48$ $r_{35} = .44$ $r_{45} = .47$
21. King and Homan (27), 1918	64 72 110	Elementary school children grades V-VIII High school pupils Juniors and Seniors in Liberal Arts College, University of Iowa	Auditory memory for prose, each test given for immediate and delayed recall. Included a long, medium, and short passage of each of 3 types of material: 1. Descriptive 2. Historical 3. Narrative Also scholastic ranks	Not reported	r of each test with scholastic rank in each group, range +.06 to +.55 (one —r, value not specified), average +.34

TABLE I—CONTINUED.

Reference	Subjects N	 Description	Tests Used*	Reliability Coefficient	Intercorrelations Computed†
22. Achilles (2) 1920	I : 96	Adults, mostly students. Also a few of heterogeneous occupations.	Recall (method of retained members) and recognition of visually presented lists of: 1. Words 2. Nonsense syllables 3. Geometrical forms 4. Proverbs	Not reported	Average r between recall and recognition of same material: +.23 (adults), +.21 (children): Average r of recall tests with each other +.19 (adults), +.10 (children). Average r of recognition test with each other +.36 (adults), +.18 (children).
	II : 285	School children, grades IV-VIII			
	III : 19	Insane patients			
23. Carothers (10), 1922	100 (rel. coeff. on only 45)	Barnard College Freshmen	1. Auditory digit span 2. Visual memory for words 3. Visual memory for proverbs 4. Visual recognition of words 5. Visual recognition of proverbs Also school grades, and other tests of association, learning, etc.	.83 .18 .48 .33 .73	All intercorrelations given. Average r of each memory test with (A) other memory tests, (B) all other tests, (C) School grades: A B C (1) = .07 .17 .16 (2) = .39 .13 .14 (3) = .40 .21 .23 (4) = .37 .13 .17 (5) = .35 .16 .18

TABLE I—CONTINUED.

Reference	*Subjects* *N*	*Description*	*Tests Used**	*Reliability Coefficient*	*Intercorrelations Computed†*
24. Lee (30), 1925	310	School children, grades III-VIII, age 7 to 16, about ¼ of total N were boys, the rest girls. Most children of foreign-born parentage	A. Tests of recall (method of retained members) and recognition for: 1. Pictures 2. Words 3. Forms 4. Syllables All tests given with intervals of 30 minutes and 24 hours. Also relearning tests after 24 hours. B. National Intelligence Test (N. I. T.)	Not reported	Average r of tests of each material with National Intelligence Test, as follows: I—Recall tests II—Recognition test I II (1) = .52 .34 (2) = .49 .27 (3) = .30 .19 (4) = .25 .26 (Av.) = .39 .26
25. McGeogh (32), 1925	I : 44 II : 58	Normal school children Sub-normal children in ungraded classes	A. 3 Aussage tests, each tested by narrative and by interrogatory method B. National Intelligence Test and Army Alpha	Not reported	r's of intelligence test scores with each of the 3 tests by each method given for each group. Range —.27 to +.58; tendency for negative relation in normal and positive in subnormal.
26. Jones and English (24), 1926	56	College students of both sexes	Auditory presentation of a story of 91 words (31 "ideas"): 1. Single presentation, subject told to recall ideas, not words 2. Continued presentation until subject could repeat verbatim	Not reported	$r_{12} = .328 \pm .08$

TABLE I—CONTINUED.

Reference	Subjects N	Description	Tests Used*	Reliability Coefficient	Intercorrelations Computed†
27. Woodrow (50), 1927	106	College sophomores	1. Rote memory for poetry: time required to learn 2. Rote memory for prose: time required to learn 3. Memory for sentences 4. Turkish-English vocabulary 5. Memory for dates and events (paired) 6. Auditory memory span for consonants (All tests except 6 were visual)	.67 ± .05 .49 ± .07 .48 ± .07 .60 ± .06 .70 ± .05 .55 ± .07	All intercorrelations given: range +.06 to +.91, average + .38
28. Lemmon (31), 1927	About 100	Columbia College undergraduates	1. Logical memory for prose passage (visual) 2. Auditory paired associates, words 3. Visual paired associates, words Also Thorndike Intelligence Examination for High School Graduates, 3 learning tests, and reaction time (simple and discriminative)	.60 .85 .94	Reports r of each memory test with reaction time. r with simple R.T. = .17 to .20; r becomes lower and negative as complexity of reaction increases.
29. Garrett (13), 1928	158	Columbia College undergraduates Age: M=19-4 S. D.=2	1. Digit span (visual) 2. Digit span (auditory) 3. Paired associates, words (visual) 4. Paired associates, words (auditory) 5. Logical memory Also Thorndike Intelligence Examination for High School graduates, and 3 learning tests.	.68 .80 .95* .90* .60 *Correction made in r for skewness	r's of memory and learning tests with "Intelligence" test range from —.12 to +.59, average +.20; using memory tests only, average r = +.16. Multiple R of memory tests with "Intelligence" test =.52 (for further discussion *cf.* page 23).

TABLE I—CONTINUED

	Subjects				
Reference	*N*	*Description*	*Tests Used**	*Reliability Coefficients*	*Intercorrelations Computed†*
30. Kelley (26), 1928	140 66 M 74 F	School children, grade VII, age: M = 12.94 S. D. = 1.048	Visual recognition (in correct sequence) of: 1. Words 2. Numbers 3. Meaningful symbols (forms) 4. Meaningless symbols Also tests designed to measure mainly verbal, numerical, and spatial ability, and speed	 .8704 .6709 .7772 .7826 (Above reliabilities are averages of r's for 7th and 3rd grades	All the intercorrelations for each group reported. Intercorrelations of memory tests range .4462 to .7169, average .6135 (7th grade) and range .4052 to .7055, average .5407 (3rd grade) (For further discussion *cf.* page 23)
	110	School children, grade III, age: M = 9.13 S. D. = 1.021			
	107	Kindergarten children, age range 3-6 to 6-3			
31. Schneck (34), 1929	187	College students, practically all juniors, very homogeneous with respect to race, social status, home environment, etc.	Visual paired associates, including: Word-word Picture-picture Word-nonsense syllable Geometrical form-digits All these materials combined into a single test of 40 items. Also tests of "Verbal" and "Numerical" abilities from which were estimated central "V" and "N" scores for each subject.	.75	r with V = .114 r with N = .171
32. Ullert and Fischler (43), (1929)	80 40 M 40 F (separate r's for each sex)	School children, age 12	1. Auditory memory for words 2. Auditory digit span 3. Auditory memory for sentences 4. Visual memory for pictures of common objects 5. Recognition of geometrical forms	Not reported	Intercorrelations range from —.38 to +.47, average +.08

common to all three, by Spearman's formula for r_{ag}.[1] These correlations were found to be:

$r = .37$ for verbal memory and g
$r = .52$ for auditory memory and g
$r = .47$ for visual memory and g

He then computed the "specific correlations" between the pools, i.e., the correlations with g partialed out. These correlations are:

r between auditory and visual memory $= .27 \pm .048$
r between auditory and verbal memory $= .19 \pm .052$
r between visual and verbal memory $= .13 \pm .052$

Since these residual correlations are significantly greater than zero, Carey concludes that they indicate the presence of a "small general memory factor," in addition to Spearman's g. Garrett (Table I—No. 29) reports all the tetrad differences with the correlations obtained from his five memory and three learning tests. The median deviation from zero of the obtained distribution of tetrad differences was then evaluated in terms of the P.E. of the entire distribution. Although the obtained median tetrad difference was slightly larger than the theoretical P.E., on analysis this was found to be due to the close similarity of some of the tests, introducing group factors. It was therefore concluded that there was a general factor through all the tests. Partialing out Thorndike Scores (taken as an approximate measure of Spearman's g) reduced the average intercorrelation to .11, still significantly above zero. It was suggested on this basis that there is a small memory factor apart from g. Kelley (Table I—No. 30) reports the tetrad differences computed from the correlations of his tests of memory, reading, arithmetic, and space relations. An analysis of group factors, indicated by the tetrads, is given on the basis of a criterion stated in proposition No. 16 (Kelley, 26 pg. 69 ff.). Estimates of the weights with which each of a number of factors, including memory ("delta factor"), entered into performance in each test were then obtained by a series of approximations. These factor values are given for each of the populations used. Kelley finds a large "alpha" factor running through all his tests, which he credits to the heterogeneity of his group with respect to maturity, sex, race, etc. The present study is a more detailed experimental attack on Kelley's "delta" factor, memory. The "alpha" factor is experimentally controlled by the use of a homogeneous group.

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[1] $r_{ag} = \sqrt{\dfrac{r_{ab}\ r_{ac}}{r_{bc}}}$

Critique of Previous Studies

An examination of Table I, and the accompanying discussion suggests a number of inadequacies or defects in previous studies which make any conclusive evaluation of the results extremely dubious. Perhaps the most fruitful and suggestive conclusion that can be drawn from such a survey of the literature is an enumeration of just those defects in methodology and technique which make any conclusions regarding the presence of a memory factor impossible. One or more of the following criticisms could be offered against any of the studies reported.

1. The use of small samplings: The size of N affects P.E.$_r$ and P.E.$_t$ very markedly. If a P.E. is extremely large, it merely shows that our determination of the correlation coefficient, or tetrad difference, as the case may be, *may differ very widely* from the true value; but it hardly justifies a conclusive evaluation of the obtained value in terms of such a P.E.
2. The use of samplings heterogeneous with respect to age, sex, racial or national background, educational and social status, etc. Column III of Table I gives adequate evidence that this criticism applies to a large number of studies. The effect of heterogeneity on the correlations obtained has been discussed in Chapter I.
3. No reliability coefficients are reported in a number of studies. Since many of the memory tests used are very short, the reliabilities are probably quite low, thus lowering the intercorrelations obtained. In several cases, the reliability coefficients are reported, but are fairly low, and hence the resulting corrections for attenuation very large. In such cases it seems rather dangerous to work with results which *might* have been obtained had the reliabilities of the tests been perfect, and which nevertheless have been *estimated* from results obtained with highly unreliable tests. The only safe procedure in such cases seems to be the construction of new tests which are more reliable in the first place.

4. The large majority of studies which report only correlation coefficients can at best be only suggestive, not conclusive. Some further criterion is necessary in establishing the presence or absence of group factors.
5. Studies using only tests of memory can at best only show the presence of a central memory factor, but cannot show its independence from other variables, or from "general capacity." Non-memory tests must be included to test the independence of a possible memory factor.
6. The tests used are frequently complex with respect to the capacities involved. This situation obviously complicates the relationships and makes evaluation of results more difficult and indirect. The tests should be as far as possible measures of sheer retentivity.
7. The selection of tests and treatment of results in several studies is such that, although the presence or absence of a general factor through all the tests may be established, no light can be thrown on the presence of narrower group factors. The latter would be especially useful when negative results are obtained regarding the presence of the more inclusive factor. This point has been discussed more fully in Chapter I.
8. The use of the formula for obtaining the P.E. of an entire distribution of tetrad differences has been criticized by Kelley (26), on the grounds that it assumes a normal distribution of the tetrad differences. The actual form of the distribution, as Kelley points out, is probably not normal, due to the correlation of the chance errors in the correlation coefficients, causing the chance errors in the tetrads also to be correlated. This shorter technique has nevertheless been used in most studies as the final criterion in evaluating the obtained tetrad differences.
9. Spearman's formula for the correlation of a test with what is common to it and a number of other tests (r_{ag}) has been used in detecting group factors. This is hardly justifiable, since the formula assumes the absence of any such group factors in its derivation.

CHAPTER III

Procedure

I. Subjects

The group of subjects finally used consisted of 225 students at the College of the City of New York. The total number of subjects taking the tests was 315. The records of ninety subjects were discarded either because of incomplete record due to absence or because they did not fulfill the qualifications required to maintain the desired homogeneity in the group. In order to obtain concrete evidence on the homogeneity of the group, the following questionnaire was filled out by each subject.

Data Sheet—A

Name .... Class...................

Age: Years..... Months..... Place of Birth.............

Mother's Birthplace......... Father's Birthplace.........

Is any language other than English spoken at home?........

Father's Occupation...................................

Father's Education: Elementary School...................

High School.................. College..................

Are you Hebrew?.......................................

Do you have any part-time employment while at college?.....

If so, how many hours a week does it occupy?.............

The results of this questionnaire have been tabulated and are presented in Table II. It will be seen that the records of a few students who fall outside of the general group with respect to some one category were not discarded. These results have all been evaluated in terms of the mean and standard deviation of the group. The records of these subjects were kept *only* when the subject's score in *each* test fell within one standard deviation from the mean of the group. The inclu-

TABLE II.

ANALYSIS OF SUBJECTS.

Class		Age	Birthplace		Father's Birthplace		Mother's Birthplace	
Junior	214	M = 19.7970 years	U. S. A.	190	Russia	109	Russia	103
Upper Sophomore	8	S.D. = 1.6157 years	Russia	17	Austria	38	Poland	35
Low Senior	3	Range = 16.6667 to 28.5833 years	Poland	35	Poland	30	Austria	34
		Sk = —5.3859	Austria	34	U. S. A.	20	U. S. A.	26
		σ_{sk} = 1.6588	Balkans	20	Balkans	19	Balkans	20
		Sk/σ_{sk} = —3.2469	Germany	2	Germany	4	Germany	2
		(piling at lower end)	Italy	2	Italy	2	Italy	2
			England	2	England	2	England	2
			Palestine	1	Palestine	1	Palestine	1

Hebrew		Other Language Spoken at Home		Father's Education		Father's Occupation		Hours of Outside Employment Per Week	
Yes	221	None	117	None	43	Professional	10	0	96
No	4	Yes (not specified)	47	Elem.	127	Salesman, real estate, insurance	26	1- 4	23
		Yiddish	57	H. S.	39	Merchants, Shopkeepers	69	5- 9	30
		German	4	College	16	Clerical	15	10-14	39
						Tailor, Furrier, Clothier	63	15-19	15
						Skilled labor	36	20-24	18
						Unskilled labor	6	25-29	4
								30-34	3
								35-39	0
								40-44	3
								45-49	4

sion of these scores would obviously not disturb the desired homogeneity.[2]

II. The Tests

The following eight memory tests were used. All were tests of immediate memory for visually presented material.

1. Paired Associates: word—word.
   All the words were simple four-letter English words.
2. Paired Associates: picture—number.
   Pictures of common objects, approximately 3 x 3 inches, in black and white were paired with two-place numbers. The pictures were cut from newspapers and magazines. In constructing the two-place numbers, all digits except zero were used. Especially familiar combinations, such as 25 and 75 were omitted.
3. Paired Associates: form—number.
   Geometrical forms, approximately 3 x 3 inches were drawn in India ink on white cards, and paired with two-place numbers as in test 2. In constructing the geometrical forms, care was taken to make the forms sufficiently different from each other in order not to necessitate fine discriminations.
4. Paired Associates: color—word.
   Triangles, circles, squares, and lozenges, in red, green, blue, yellow, orange, and purple or combinations of any two of these colors were paired with four-letter English words. The colored forms were cut out of Dennison's gummed papers, dull finish (numbers 122, 124, 125, 126A, 120, and 140).
5. Digit span: four parallel forms of this test were used, each ranging from four to thirteen digits.
6. Retained members: four-letter English words.
7. Recognition of geometrical forms, similar to the forms used in test No. 3.
8. Recognition of three-letter nonsense syllables:
   The nonsense syllables were taken from a list published by Glaze (18). The particular syllables used were selected from a list of 101 syllables found by Glaze to have zero associative value for his group of subjects.

All the test materials were glued on rectangular white card-board cards. Black two-inch letters[3] and numbers were used throughout. Each of the recall tests contained a total of forty items, divided into shorter sub-tests, as described further (pg. 30). Each of the two recognition tests contained forty "old" and forty "new" items.

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[2] An additional advantage of using this group of subjects lies in the fact that the group is similar to the group used by Schneck (34) in his study of V and N. The results of the two studies are therefore directly comparable.

In addition to the eight memory tests described above, the following three tests of other traits were used, making a total of eleven tests.

1. Multiple Choice Vocabulary Test:
   The test used was the vocabulary test used by Schneck (34) and found by him to correlate .90 with the central "verbal" factor.
2. Arithmetic Reasoning Test:
   This was also one of the tests used by Schneck and found to correlate .75 with the central "number" factor.
3. Minnesota Paper Form Board Test, forms A and B.
   This test is described by Anderson (3), and was used in the attempt to get at a measure of a possible "spatial ability."[4]

III. *Preliminary Experimentation*

The purpose of the preliminary investigation was manifold. It was desired (1) to settle details of procedure and to decide upon the best technique of administering the tests; (2) to eliminate undesirable items; (3) to arrange items in a rough order of difficulty; (4) to find the optimum length of presentation series for each test which would give no zero or perfect scores and as nearly as possible a normal distribution. The subjects used in the preliminary experimentation were about 180 Barnard College and Columbia University Extension students in beginning and educational psychology.

The following arrangements were tried for each recall test and the resulting distribution of scores for each tabulated.

1. Single series containing all 40 items.
2. Two series of 20 items each.
3. Four series of 10 items each.
4. In a few cases, two presentations of series of 20 items were tried.

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[3] Wilson's gummed letters and numbers, No. P33, supplied by Tablet and Ticket Co., 115 East 23rd Street, New York City.

[4] The Thurstone Spatial Relations Tests A and B were also used, but the results dropped because of difficulty in understanding directions and low reliability coefficients.

With the two recognition tests, the only arrangements tried were:

1. One series of 80 items (40 old and 40 new).
2. Two series of 40 items (20 old and 20 new).

The lengths of series finally chosen for each test are:

1. Word—word: two series of 20 items.
2. Picture—number: two series of 20 items.
3. Form—number: four series of 10 items.
4. Color—word: four series of 10 items.
5. Digit span: four parallel series, each ranging from 4 to 13 digits.
6. Retained members: one series of 40 items.
7. Form—recognition: one series of 80 items.
8. Syllable—recognition: two series of 40 items.

Each card was numbered on the reverse side for presentation order and test order.

IV. Testing Procedure

All tests were given by the group method. The memory tests and the Minnesota Paper Form Board Test were given in seventeen laboratory sections each of fifteen to twenty students. All this testing was done by two examiners,[5] the regular instructors in their respective laboratory sections. The tests were taken by the students as part of the regular laboratory work of the course. Every precaution was taken to prevent cheating.[6] The vocabulary and arithmetic reasoning tests were given in two large lecture sections, each consisting of about 150 students.[7] Table III gives hour of day, number of cases, and mean score in each of the memory tests for each of the sixteen[8] laboratory sections included in the final results. These data were collected as a check on the uniformity of conditions under which the tests were given. The means and standard deviations of the entire group in each test are also given. It will be seen that the means of each section

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[5] Prof. H. D. Marsh and Mr. John G. Peatman.

[6] Only two records had to be discarded on this account.

[7] These tests were given by Dr. M. R. Schneck.

[8] One of the sections was dropped, since, through lack of time, some of the memory tests were not given in it.

TABLE III.

RESULTS FOR EACH SECTION.

Section	*N*	*Word-Word*	*Picture-Number*	*Form-Number*	*Color-Word*	*Syllable Recognition*	*Form Recognition*	*Digit Span*	*Retained Members*	*Hour of the Day**
T	20	9.90	12.70	11.25	9.20	45.20	52.80	9.32	18.25	Tu 3-5 P.M.
X	17	10.18	11.59	12.59	9.76	46.59	52.82	9.03	19.52	Th 3-5 P.M.
Y	19	12.00	15.36	15.00	11.36	44.42	56.31	9.18	18.31	Fr 3-5 P.M.
DD	18	12.33	11.55	12.00	10.94	42.22	51.78	9.33	17.66	M-W-12-1
E	17	11.35	14.47	14.70	10.29	38.94	57.52	8.82	18.17	M-W-1-2 P.M.
CC	17	14.47	15.23	14.64	11.52	45.52	58.35	9.32	19.70	Tu-Th-11-12
LL	19	12.57	12.78	14.57	11.21	47.89	52.10	9.84	20.89	Tu-Th-10-11
Q	16	14.31	11.56	11.56	9.68	43.12	51.62	9.20	16.56	Tu-F-1-2 P.M.
R	16	8.93	12.93	11.87	9.43	45.63	51.25	9.00	16.06	Tu-Th-2-3 P.M.
M†	16	11.93	14.00	10.81	9.62	46.87	50.50	9.75	18.87	W-F-12-1
B	12	12.91	12.41	9.58	10.16	40.66	54.66	9.62	15.58	M-W-10-11
C	19	16.10	13.31	10.47	10.63	45.57	47.05	9.07	18.94	Tu-Th-12-1
D	16	13.25	15.87	12.75	12.18	45.37	56.75	9.05	22.00	M-W-10-11
F	15	12.86	13.26	12.06	9.40	49.46	51.33	9.55	17.93	M-W-2-3 P.M.
K	13	14.92	16.76	15.00	9.85	46.92	52.76	10.02	19.30	Tu-Th-9-10
L	15	14.00	16.13	15.93	11.26	52.13	56.26	9.60	20.73	Tu-Th-10-11
Group Mean		12.51	14.24	12.93	10.54	45.23	53.58	9.31	18.79	
Group S. D.		6.94	6.69	5.79	4.52	11.01	9.37	1.09	4.95	

* All hours are A.M., unless otherwise indicated.

† One of the two examiners gave all the tests in the above nine sections, the other in the following seven sections.

are in all cases within 1 S.D. of the mean of the entire group. The statistical evidence for the uniformity of results is therefore satisfactory.

The tests occupied a total of approximately six hours, including four one-hour laboratory sections and two lecture hours. The testing was extended over a period of four months, from February, 1930, to May, 1930. The following testing schedule was followed in all the sections.

TESTING SCHEDULE

Period	*Tests, in the Order Given*
I	1. word—word 2. picture—number
II	1. form—number 2. form—recognition 3. syllable—recognition
III	1. color—word 2. digit span 3. retained members
IV	Vocabulary
V	Arithmetic
VI	Minnesota, form A, followed immediately by form B.

The following points were considered in deciding upon this sequence:

1. Facilitation in comprehension of directions.
2. Beginning with easier tests and tests in which directions are easier to understand.
3. Avoiding, as far as possible, the occurrence during the same period of tests using similar material, in order to avoid interference effects.

The specific directions to be followed in administering each test were typewritten and a copy given to each examiner. The cards were kept in piles on the examiner's desk, face downward. The exposure time was three seconds for each card in all memory tests except the digit span; in the latter, one second was allowed for each digit in the series, the exposure time therefore ranging from four to thirteen seconds. Exposure time was controlled by the beats of a metronome, set at 60.

The subjects were provided with mimeographed data sheets for recording responses in each of the memory tests. These sheets were used to facilitate writing and scoring of responses as well as to keep the testing conditions more uniform.

In giving the vocabulary and arithmetic reasoning tests the procedure used by Schneck (34) was followed throughout. The Minnesota Paper Form Board tests were given with a time-limit of 15 minutes for each form. The directions were slightly modified from those used by Anderson (3) in order to adapt the test to an adult group.

V. Scoring

The paired associates and retained members tests were scored in terms of the total number of items correct. The recognition tests were scored by subtracting twice the number wrong from the total number of items.[9] In the digit span test, the subject's span in *each* of the four parallel forms was taken as the longest series of digits correctly reproduced in the correct order; no partial credits were given, as all these methods were considered too arbitrary and would probably yield results no more reliable than the crude span. Since there were only four forms of the digit span test, the method of constant stimuli, suggested by Guilford and Dallenbach (19) could not be applied. The total score on the digit span test was taken as the average of the crude span from each of the four forms. The vocabulary, arithmetic reasoning, and Minnesota Paper Form Board Tests were scored in terms of the total number of items completely correct. In the Minnesota Test, an item was scored as correct when all the necessary lines were drawn in the correct direction, with a deviation of not more than one-eighth of an inch from the correct position. These deviations of one-eighth of an inch were allowed in order not to penalize subjects for habitual carelessness, as this would have been an irrelevant factor in testing for spatial ability. Deviations in position due to carelessness were distinguished by being more general, occurring throughout an individual's paper; these deviations rarely exceeded the limit of one-eighth of an inch; deviations greater than this were confined to isolated figures and probably indicated actual lack of spatial orientation in the cases in which they occurred.

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[9] No omissions were allowed in the recognition tests.

In order to compute reliability coefficients, two scores were obtained for each test. On paired associates, recognition, vocabulary, and arithmetic reasoning tests, odd and even items were used in obtaining the two scores. In the retained members test, the subject was told simply to write the words as he recalled them, in any order; hence, we could not score odds against evens as they appeared on the test blanks, since this would give a spuriously perfect reliability. The method followed in this case was to refer each word on the subject's list back to the original presentation list, and score it as odd or even according to the order of the original list. In the digit span test, the first and third forms were combined against the second and fourth. This arrangement was followed in order to neutralize the combined effects of practice and fatigue on the scores. The actual averages obtained on each of the four forms further justifies this arrangement.

Digit Span Averages:

Form	I	II	III	IV
Average span	8.999	9.555	9.290	9.186

In computing the reliability of the Minnesota Test, the subject's scores on Form A and Form B were correlated.

CHAPTER IV

THE RESULTS

I. Evaluation of the Tests

In Table IV are reported means, standard deviations, skewness, and reliability coefficients of each of the distributions of test scores. All of these data are based on the 225 records kept in the final results. The measures of skewness are given in order to give some idea of the normality of the distributions worked with. Since the Pearson coefficient of correlation assumes normality of distribution in its derivation, it seems that any study depending as much on correlation results as the present study should test its distributions for normality. No measure of kurtosis of the distributions is given, since this is obviously that of the normal curve in every case. With respect to skewness only could there be any doubt regarding the normality of the distribution. The measure of skewness used is, $Sk = P_{.50} - \frac{1}{2}(P_{.90} + P_{.10})$ and this was evaluated in terms of its standard error, $\sigma_{sk} = .59914 \frac{D}{\sqrt{N}}$ (Kelley, 25). A significant skewness is indicated when $\frac{Sk}{\sigma_{sk}}$ is greater than 3. Positive skewness as obtained by this formula would indicate a piling of scores at the upper end of the distribution, negative skewness a piling at the lower end. The reliability coefficients for the total tests were computed from the correlation of halves by the Spearman-Brown formula.

All the memory tests except retained members and syllable recognition show a tendency towards negative skewness, indicating a slight piling or jamming of scores at the lower end of the distribution. Such a jamming would indicate that the tests are slightly too difficult for the group of subjects used. However, the skewness, when evaluated in terms of its standard error, appears to be insignificant in all cases except the word-word test. Even in this case, the skewness is just barely significant, and not very marked. This skewness would tend to *lower* the reliability coefficient of the test, as well as its correlations with other tests. Since this test has the highest reliability coefficient of all the memory tests, the effect of the skewness is probably negligible. The tests are all fairly

TABLE IV*

Means, Standard Deviations, Skewness, and Reliability

	M	*S.D.*	*Sk*	σ_{sk}	$\frac{Sk}{\sigma_{sk}}$	*Reliability Coefficient*
1—Word—Word	12.5111	6.9424	—2.3215	.7275	—3.1911	.8802
2—Picture—Number	14.2356	6.6854	—1.0872	.7153	—1.5199	.8348
3—Form—Number	12.9289	5.7915	—1.0858	.5666	—1.9163	.7976
4—Color—Word	10.5422	4.5166	— .7739	.4583	—1.6886	.6306
5—Retained Members	18.7867	4.9493	+ .3403	.5325	+ .6391	.7277
6—Digit Span	9.2900	1.0886	— .0565	.4713	— .1199	.7449
7—Form Recognition	53.5822	9.3745	— .0195	.9590	— .0203	.5386
8—Syllable Recognition	45.2267	11.0121	+ .7462	1.1879	+ .6282	.6750
9—Vocabulary	76.5156	15.5325	+ .0948	1.6608	+ .0571	.9154
10—Arithmetic	28.4578	7.0205	+ .2074	.7523	+ .2757	.8970
11—Minnesota	68.9467	15.2144	+1.8000	1.6242	+1.1082	.8956

* The means, S.D.'s and correlations of halves were computed by the Columbia University Statistical Bureau.

reliable, considering their short duration, except the form-recognition test. This test, because of its low reliability coefficient, has been dropped from the final evaluation of results (*cf.* pg. 40).

A few comments should be added regarding the non-memory tests used. All the subjects whose records were retained, completed the vocabulary test within the time allowed, thus showing it to be primarily a power test, as was desired. This was not strictly true, however, of the arithmetic reasoning test. The papers were examined with a view to discovering for what per cent of the subjects the test had been a speed test. In order to exclude somewhat the papers on which items might have been omitted simply because they were too difficult to attempt, an incomplete paper was defined as one on which two or more items were omitted at the end, or on which an entire section was omitted, to which presumably the subject had intended to return at the end, but was prevented by lack of time. When so defined, the number of incomplete papers was 116 out of a total of 298, or 39%. The number of papers with no omissions at all was 120, or 40%, 60% having at least one omission. In so far as the arithmetic reasoning test was a speed test, its reliability coefficient computed by the method of odds and evens is too high. In the case of a pure speed test, such a method of computing the reliability coefficient obviously could not be used at all, since the reliability coefficient would then be practically 1.00, through purely spurious influences. The Minnesota paper form board test proved to be even more markedly a speed test for this group.[1] There were no papers without omissions. The average number of omissions was 31.7956 and the average number of errors 11.0133. The correlation of errors and omissions was —.1580 ± .0438, showing that the two are probably not related in any significant way; the faster person on this test does not tend to be either more or less proficient than the slower. Considering Form A and Form B separately, there is a fairly consistent tendency for errors to increase and omissions to decrease on the second form.

	Average No. of Errors	*Average No. of Omissions*
Form A	4.7822	18.9600
Form B	6.2311	12.8356

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[1] It will be recalled that the reliability coefficient for this test was not computed by correlating odds and evens but by correlating alternate forms. (Cf. page 34, Chapter III.)

The subject seems to increase his speed at the expense of accuracy, probably because he realizes how little he accomplished on Form A during the time allowed. Because of this situation, the results obtained with the two forms are not strictly comparable, when Form B is given immediately after Form A.

II. Intercorrelations of the Variables

In Table V are presented all the intercorrelations of twelve variables, including eight memory tests, three non-memory tests, and age. The last variable was included in order to hold age constant by the partial correlation technique.[2] The obtained correlations with age are all very low negative. Negative correlations with age would have been expected throughout, in accordance with the general finding that the younger students in a class are usually the brighter. The obtained correlations with age in the present study are practically zero, being well within 4 P.E.[3] A tentative explanation of this result may be offered on the basis of the negative skewness of the age distribution (*cf.* Table II—pg. 27). Since the other distributions are quite normal, the skewness of the age distribution would tend to *lower* the correlations of age with the other variables.

All the correlation coefficients, including those with age, have been corrected for attenuation. Both corrected and uncorrected correlations are given in Table V. The uncorrected coefficients are above the diagonal extending from the upper left to the lower right hand corner; the corrected coefficients are below this diagonal. The corrections for attenuation range from .0007 to .2465, averaging .0684. In view of the fact that these corrections are so large, it was considered advisable to use both raw and corrected coefficients in further computations.

The correlations with age partialed out are given in Table VI. Since all the correlations with age are of like sign, all being negative, partialing out age usually has the effect of

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[2] This was simply an additional precaution in securing homogeneity; the group was already fairly homogeneous with respect to age, as is shown in Table II, pg. 27.

[3] The correlations with age obtained by Schneck (34) on a similar group were larger.

TABLE V.

Raw and Corrected Pearson Coefficients of Correlation with Twelve Variables.*

	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*	*11*	*12*
1. Word-word		.4984	.4090	.4416	.4885	.1495	.2837	.2593	.1365	.0771	.0301	—.0800
2. Picture-number	.5814		.5455	.3627	.3418	.0960	.3602	.2177	.0048	.1427	.0630	—.0872
3. Form-number	.4881	.6685		.4400	.3620	.1268	.3102	.3878	.0400	.1500	.2158	—.0514
4. Color-word	.5927	.4999	.6204		.5175	.1100	.2982	.2822	—.0067	.0752	.1236	—.1895
5. Retained members	.6104	.4385	.4793	.7640		.1422	.2780	.3145	.0526	.1453	.1236	—.1076
6. Digit span	.1846	.1218	.1645	.1605	.1931		—.0138	.1382	—.0231	.2152	.0428	—.0643
7. Form-recognition	.4121	.5372	.4733	.5117	.4441	—.0218		.1064	.0512	.1515	.2846	—.1003
8. Syllable-recognition	.3364	.2900	.5285	.4325	.4487	.1949	.1765		.1720	.1150	.1081	—.1134
9. Vocabulary	.1521	.0055	.0471	—.0088	.0645	—.0280	.0729	.2188		—.0121	.0597	—.0766
10. Arithmetic	.0868	.1650	.1773	.1000	.1798	.2633	.2180	.1478	—.0134		.2961	—.1907
11. Minnesota	.0339	.0729	.2553	.1645	.1531	.0524	.4097	.1390	.0659	.3304		—.1480
12. Age	—.0853	—.0954	—.0576	—.2386	—.1261	—.0745	—.1367	—.1380	—.0801	—.2014	—.1564	

* Raw coefficients above the diagonal, corrected coefficients below the diagonal.
The raw coefficients were computed by the Columbia University Statistical Bureau.

lowering the coefficients,[4] unless the original correlation is negative; in this case the resulting partial correlation is still higher negative. The age correction is in most cases very slight, ranging from .0011 to .0454, and averaging .0103.

In order to give a general idea as to the significance of the correlations obtained, the probable errors[5] of the highest and lowest correlation coefficients in Table VI were computed. These P.E.'s are .0450 for the lowest coefficient (.0021, between vocabulary and picture-number) and .0189 for the highest (.7619, between color-word and retained members). Furthermore, with an N of 225, a correlation coefficient must be approximately .17 or higher in order to be significant, *i.e.*, greater than 4 P.E._r.

The average intercorrelation of the eight memory tests is .2948 using raw coefficients, and .3995 using corrected coefficients. The digit span test gives the lowest correlations with the other memory tests, its average correlation with the other memory tests being .1070 with raw coefficients, and .1425 with corrected coefficients. On the basis of this result it seems probable that digit span is not primarily a test of memory for an adult group of subjects, performance on it probably depending on incidental factors, such as attention, an active attitude, desire to do well on the test, etc. The memory ability required for a successful performance on this test is probably so slight as to fall well below the general level of the group. In a group such as that used in the present study, therefore, individual differences in digit span are probably due to factors other than memory ability. If we eliminate digit span for these reasons, and form recognition because of its low reliability coefficient, the average intercorrelation of the remaining six memory tests is .3912 for raw coefficients

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[4] One exception to this was the correlation between form-number and color-word, which was raised from +.6204 to +.6258, when age was partialed out. This is due to the fact that the correlation of form-number with age is nearly 0 (—.0576) and that of color-word with age fairly high (—.2386). This produces the following situation:

$$r_{12.3} = \frac{r_{12} - \overset{(0)}{r_{13}}\ \overset{(\text{high})}{r_{23}}}{\underset{(1.00)}{\sqrt{1 - r^2_{13}}}\ \underset{(\text{low})}{\sqrt{1 - r^2_{23}}}} = \frac{r_{12} - 0}{\text{low decimal}} > r_{12}$$

[5] $$\text{P.E.}_r = \frac{.6745\ (1 - r^2)}{\sqrt{N}}$$

TABLE VI.

INTERCORRELATIONS WITH AGE PARTIALED OUT (AFTER CORRECTING FOR ATTENUATION).

	1	2	3	4	5	6	7	8	9	10	11
1. Word-word		.5780	.4858	.5916	.6066	.1794	.4057	.3289	.1463	.0713	.0209
2. Picture-number			.6672	.4936	.4319	.1156	.5316	.2808	—.0021	.1495	.0590
3. Form-number				.6258	.4766	.1609	.4697	.5266	.0427	.1695	.2498
4. Color-word					.7619	.1474	.4980	.4155	—.0288	.0546	.1326
5. Retained members						.1857	.4344	.4390	.0642	.1589	.1362
6. Digit span							—.0331	.1870	—.0342	.2542	.0413
7. Form-recognition								.1606	.0628	.1963	.3969
8. Syllable-recognition									.2105	.1237	.1200
9. Vocabulary										—.0154	.0542
10. Arithmetic											.3089
11. Minnesota											

and .5156 for corrected coefficients. This result gives fairly good indication of the presence of a common factor through the memory tests, and makes the application of further techniques to establish the presence of this factor and its approximate importance in the various memory tests seem fruitful. These further computations are given in section III of the present chapter.

The correlations found between the memory tests and the three non-memory tests offer equally suggestive evidence for the independence of the memory factor. The average correlation with the memory tests are as follows:

	Raw	Corrected
Vocabulary	.0534	.0576
Arithmetic	.1325	.1473
Minnesota	.1240	.1446

All these average correlations are less than 4 $P.E._r$, although some of the individual correlations are significant. Some of these individual correlations bring out rather interesting relationships and will be discussed separately. The highest correlation of vocabulary is .2105 ± .0430 with syllable recognition. The fact that the vocabulary test is a multiple choice test, depending on *recognition* of the correct synonym, may throw some light on this relationship. The next highest correlation of vocabulary (.1463 ± .0440) is with word-word, as might be expected because of similarity in content. The highest correlation of the arithmetic reasoning test is .2542 ± .0421 with digit span, which is easily attributable to overlapping of content; this is also the highest correlation of digit span with any other test. The highest correlations of the Minnesota test with the memory tests are .3969 ± .0379 with form recognition and .2498 ± .0422 with form-number. These results are also what would have been expected on the basis of content. The correlation of — .0154 ± .0450 between vocabulary and arithmetic reasoning is considerably lower than that of .2521 obtained by Schneck (34). The correlation of .3089 ± .0407 between arithmetic reasoning and Minnesota is interesting, but its interpretation is outside the scope of the present study.

With the above suggestive evidence on the presence and independence of a memory factor, a systematic analysis of the data with a view to establishing these results on a more solid basis will be undertaken in the following sections.

III. Preliminary Survey by Means of the Tetrad Criterion

Eliminating the form recognition and digit span tests for the reasons stated above, all the possible tetrads with the remaining six memory tests were computed. Table VII gives the tetrad differences for each set of four variables, computed from raw coefficients, and below each, the value of the corresponding tetrad difference computed from corrected coefficients. The tetrads for each set of variables have been arranged in the three columns of the table in the order of (1) t_{1234}, (2) t_{1243}, (3) t_{1342}. Several of the tetrad differences are significantly greater than zero. On further analysis, it was found that this was due to the fact that some of the tests were too similar, producing small minor group factors. Thereupon a systematic analysis of the tetrad differences was made in the attempt to locate these group factors and determine which tests should be combined in further treatment of the data. This analysis is presented in column V of Table VII. Tetrad differences may, for convenience, be classified according to three general types. (1) All three tetrads equal to zero (within $P.E._{\cdot t}$), indicating a general and specific factors, with no group factors; (2) two tetrads equal to each other and the third equal to zero, indicating in addition to general and specific factors, group factors through either or both of two pairs of variables;[6] the particular pairs of variables containing the group factors can be definitely determined by seeing which two of the three tetrads are equal to each other, according to Kelley; these pairs of variables have been indicated in column V (Table VII) whenever the tetrads are of this type. (3) None of the tetrads equal to zero or to each other; in this case, it is impossible definitely to locate the group factor or factors or even to assume a general factor; the entries in column V for these tetrads indicate simply all the pairs of variables which might possibly contain group factors, on the basis merely of the greater magnitude of one of the two products in any one of the three tetrad equations. Nothing conclusive is claimed for this analysis, especially regarding the entries for tetrads of the third type. The final test of the validity of the analysis lies in the success with which the group factors are eliminated by the combinations of those tests which presumably contain group factors. The tetrads computed with these combined tests should equal zero, if our analysis of group factors has been successful.

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[6] *Cf.* Kelley (26)—proposition No. 16, pg. 69 ff.

TABLE VII.

TETRAD DIFFERENCES OF SIX VARIABLES* WITH RAW AND CORRECTED COEFFICIENTS.

Variables	t_{1234}	t_{1243}	t_{1342}	*Probable Group Factors*
1234	+.0710	—.0216	—.0926	12 or 34; 14 or 23
	+.1219	—.0330	—.1549	
1235	+.0414	—.0861	—.1267	15 or 23
	+.0657	—.1292	—.1949	
1245	+.1070	+.0807	—.0263	12 or 45
	+.1849	+.1410	—.0439	
1236	+.1043	+.0519	—.0524	12 or 36
	+.1680	+.0850	—.0834	
1246	+.0445	+.0466	+.0021	None
	+.0734	+.0772	+.0038	
1256	+.0504	+.0681	+.0177	12 or 56
	+.0834	+.1116	+.0282	
1345	+.0518	—.0032	—.0550	15 or 34; 13 or 45
	+.0881	—.0095	—.0976	
1346	—.0559	+.0013	+.0572	None
	—.1097	—.0040†	+.1057	
1356	—.0608	+.0347	+.0955	15 or 36
	—.1061	+.0565	+.1626	
1456	+.0010	+.0047	+.0037	None
	+.0077	+.0091	+.0014†	
2345	+.1510	+.1319	—.0191	23 or 45
	+.2731	+.2380	—.0351	
2346	+.0132	+.0581	+.0449	None
	+.0173	+.1015	+.0842	
2356	+.0390	+.0928	+.0538	23 or 56
	+.0655	+.1591	+.0936	
2456	+.0176	+.0014	—.0162	None
	+.0372	+.0028	—.0344	
3456	+.0362	—.0623	—.0985	36 or 45
	+.0767	—.1265	—.2032	

* The variables are numbered as follows:

1. Word-word
2. Picture-number
3. Form-number
4. Color-word
5. Retained-members
6. Syllable-Recognition

† See discussion on page 45.

It will be readily seen from an examination of Table VII that tetrad differences computed with corrected coefficients are always larger than the corresponding tetrad differences computed with raw coefficients. There are only two apparent exceptions to this in Table VII, namely t_{1364} and t_{1564}. These apparent discrepancies are due to the fact that the correlations used in computing the second set of tetrads in Table VII are not only corrected for attenuation, but are also partial correlations with age constant. In most cases, the effect of partialing out age was insignificant. However, when the tetrad differences are themselves very small, of the order of .01 or .001 as in the case of t_{1364} and t_{1564}, the age correction stands out and reverses the effect resulting from the correction for attenuation. The two sets of tetrads in question give perfectly consistent results when only the correction for attenuation is applied, without partialing out age. The values of the tetrad differences then become:

$t_{1346} = -.1021$ $\qquad t_{1456} = +.0019$
$t_{1364} = +.0024$ $\qquad t_{1465} = +.0089$
$t_{1463} = +.1045$ $\qquad t_{1564} = +.0070$

By referring to Table VII, it will be seen that in each case the tetrad difference with corrected coefficients is larger and of the same sign as the corresponding tetrad difference with raw coefficients.[7]

The Probable Error formula used in evaluating the obtained tetrad differences is that reported by Kelley (26).[8] The P.E.

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[7] That this result must always follow, unless the tetrad difference is exactly equal to zero, can be readily demonstrated as follows:
Let t_{1234} = a tetrad difference with raw coefficients, and
t'_{1234} = the corresponding tetrad difference with corrected coefficients, then,

$$t_{1234} = r_{12}\ r_{34} - r_{13}\ r_{24}$$

Correcting each r for attenuation, we get,

$$t'_{1234} = \frac{r_{12}}{\sqrt{r_{1I}\ r_{2II}}} \cdot \frac{r_{34}}{\sqrt{r_{3III}\ r_{4IV}}} - \frac{r_{13}}{\sqrt{r_{1I}\ r_{3III}}} \cdot \frac{r_{24}}{\sqrt{r_{2II}\ r_{4IV}}}$$

$$= \frac{r_{12}\ r_{34} - r_{13}\ r_{24}}{\sqrt{r_{1I}\ r_{2II}\ r_{3III}\ r_{4IV}}} = \frac{t_{1234}}{\sqrt{r_{1I}\ r_{2II}\ r_{3III}\ r_{4IV}}}$$

Since the denominator will always be < 1, t'_{1234} will always be > t_{1234}.

[8] $$\text{P.E.}_{t_{1234}} = .6745\frac{1}{\sqrt{N}}\Big[r^2_{12} + r^2_{13} + r^2_{24} + r^2_{34} + 2r_{12}\ r_{14}\ r_{23}\ r_{34} + 2r_{13}\ r_{14}\ r_{23}\ r_{24} - 2r_{12}\,r_{13}\,r_{23} - 2r_{12}\,r_{14}\,r_{24} - 2r_{13}\,r_{14}\,r_{34} - 2r_{23}\,r_{24}\,r_{34} + t^2_{1234}\,(r^2_{12} + r^2_{13} + r^2_{14} + r^2_{23} + r^2_{24} + r^2_{34} - 4)\Big]^{1/2}$$

of the largest tetrad difference in Table VII (t_{3254}) is .0240 using raw coefficients and .0242 using corrected coefficients. The P.E. of the smallest tetrad difference (t_{1456}) is .0214 for raw coefficients and .0192 for corrected coefficients. With a given N, the P.E. differs only slightly for different tetrad differences. Several P.E.'s computed for tetrad differences in Table VII were all of the order of .02. Since the evaluation of the tetrads in Table VII serves only as a preliminary survey for the location of overlapping tests, it was deemed unnecessary to compute the individual P.E.'s for each tetrad difference. It is sufficient in this preliminary survey to know that the P.E.'s are approximately .02.

It is interesting to compare the effect of the correction for attenuation on the tetrad differences and on their respective P.E.'s. Whereas the use of corrected coefficients consistently and markedly raises the numerical value of the tetrad difference above zero, it scarcely affects the final value of $P.E._{t}$ at all. As a result, when evaluating the tetrad difference in terms of its P.E., the chances that the difference appears significantly greater than zero are greater when using corrected than when using uncorrected coefficients. When the correction is large, amounting to as much as .10 it might seriously distort the results. In view of the fact that corrected coefficients represent hypothetical results which might have been obtained under ideal conditions, it seems safer to work with the coefficients actually obtained, especially when the corrections for attenuation are large. The use of corrected or uncorrected coefficients does not in any way alter the relative magnitude of the tetrad differences, but only raises their absolute magnitude. For these reasons, in computing the final set of tetrads with combined tests, raw coefficients have been used. The computations have also been repeated with corrected coefficients; the results obtained thereby are reported merely as a check on the results obtained with raw coefficients.

IV. Evidence for a Common Memory Factor

The tests finally selected for combination, as indicating group factors most consistently, are 2 and 3 (picture-number and form-number) and 4 and 5 (color-word and retained members). The following set of variables has been used in the computation of the final tetrads:

1. word-word
2. picture-number and form-number
3. color-word and retained members
4. syllable recognition

The correlation of the individual tests were taken from Table VI. The correlations of 1 and 2, 1 and 3, 2 and 4, 3 and 4, were computed by the multiple correlation technique. The correlation between 2 and 3 was computed by Spearman's formula for the correlation of the sums of two series, equally weighted and with different standard deviations.[9] The correlation coefficients, tetrad differences, and corresponding probable errors of the tetrad differences, are given in Table VIII.

TABLE VIII

TETRAD DIFFERENCES WITH COMBINED TESTS[10]

$r_{12} = .5245$ $\quad$ $r_{23} = .4876$

$r_{13} = .5352$ $\quad$ $r_{24} = .3867$

$r_{14} = .2593$ $\quad$ $r_{34} = .3439$

$t_{1234} = -.0266 \pm .0288 = -.9236$ P.E.

$t_{1243} = +.0540 \pm .0208 = 2.5962$ P.E.

$t_{1342} = +.0808 \pm .0220 = 3.6636$ P.E.

The presence of a central factor through the tests of immediate memory seems to be indicated by the tetrad analysis presented in Table VIII. Each of the final tetrad differences is less than four times its probable error and is hence statistically not significant. One of the tetrad differences (t_{1342}), is, to be sure, just barely within the limits of four times P.E.$_t$. This seems to suggest that some group factors still remain. However, in view of the fact that the three tetrad differences, taken as a whole, do not indicate the presence of consistent or systematic group factors, and that such factors, if present, must be very small, as indicated by the size of the specific

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[9] Spearman (37)

$$r_{(a_1 + a_2)(b_1 + b_2)} = \frac{\Sigma(\sigma_a \sigma_b r_{ab})}{\sqrt{[\Sigma(\sigma^2_a) + 2\Sigma\sigma_a \sigma_a r_{aa}] \; [\Sigma(\sigma^2_b) + 2\Sigma\sigma_b \sigma_b r_{bb}]}}$$

[10] The results obtained with corrected coefficients are here presented as a check:

$r_{12} = .5929$ $\quad$ $r_{23} = .6603$ $\quad$ $t_{1234} = -.0691$

$r_{13} = .6386$ $\quad$ $r_{24} = .5332$ $\quad$ $t_{1243} = +.0542$

$r_{14} = .3289$ $\quad$ $r_{34} = .4554$ $\quad$ $t_{1342} = +.1233$

correlations (*cf.* further, Table IX), the size of the one tetrad difference in question cannot be regarded as undermining our main conclusion regarding the constitution of the four variables.

V. *Correlations with Central and Specific Factors*

The correlations of each of the four tests in the final team presented in the preceding section with what is common to the whole team, were computed by Spearman's formula[11] for the correlation of a test with *g*.[12]

$$r_{ag} = \sqrt{\frac{r_{ab}\ r_{ac}}{r_{bc}}}$$

Since there are four tests in the battery and only three at a time are used in computing r_{ag}, three values of r_{ag} will be obtained for each test. These values have been averaged in obtaining the final r_{ag} values presented in Table IX. Knowing the intercorrelations of the tests and the correlation of each with the central factor, it was then possible to compute the correlations between the specific factors in each test, *i.e.*, the intercorrelations of the tests with the central factor partialed out. The ordinary partial correlation technique was used in computing these coefficients. The values of these partial correlations are also given in Table IX. In computing the probable errors of these partial correlation coefficients, the ordinary formula for $P.E._r$ has been used, this formula giving the probable error of a coefficient of any order, total or partial.[13]

TABLE IX

CORRELATIONS WITH CENTRAL AND SPECIFIC FACTORS

Correlations with Central Factor	Intercorrelations with Central Factor Partialed Out			
$r_{1g} = .6623$	$r_{12.g} =$	.0277 ±.0450	$r_{23.g} =$	—.1863 ±.0434
$r_{2g} = .7720$	$r_{13.g} =$	.0948 ±.0446	$r_{24.g} =$	.0613 ±.0448
$r_{3g} = .7355$	$r_{14.g} =$	—.0640 ±.0448	$r_{34.g} =$	.0141 ±.0450
$r_{4g} = .4560$				

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[11] Spearman (39), pg. xvi, Appendix.

[12] The term *g* is used here to mean any general factor running through four tests, and is not *g* in Spearman's sense.

[13] *Cf.* Yule (52) and (53, pg. 352).

The correlations with the central factor are all sufficiently high to substantiate our conclusion regarding the existence of a central factor through all the tests. The correlations between the specific factors in all the tests indicate that group factors have been successfully eliminated by the combinations used. The only one of the six partial correlations which might be considered at all significant is the negative correlation $r_{23.g}$. This correlation seems to indicate that some of the "specific" factors in 2 and 3 are opposed. Even this correlation, however, is just barely significant when evaluated in terms of its probable error; hence it is very doubtful that it indicates a true relationship.

VI. Independence of the Memory Factor

It hardly seems necessary to take further steps to prove the independence of the memory factor from the factors involved in the three non-memory tests, considering that the average correlations obtained with these three tests were practically zero. Nevertheless, tetrads have been computed with the three "best" single memory tests and each of the three non-memory tests. These tetrad differences, as well as the r_{ag} of each of the non-memory tests are given in Table X.

TABLE X

TETRAD DIFFERENCES AND CORRELATIONS WITH THE CENTRAL FACTOR IN THE CASE OF THE NON-MEMORY TESTS

1. word-word
2. picture-number
3. retained members
4. vocabulary
5. arithmetic reasoning
6. Minnesota Paper Form-Board

$t_{1234} = +.0239$
$t_{1243} = -.0205$
$t_{1342} = -.0444$

$t_{1235} = +.0027$
$t_{1253} = +.0700$
$t_{1352} = +.0673$

$t_{1236} = +.0308$
$t_{1263} = +.0513$
$t_{1362} = +.0205$

$r_{4g} = .0615 \pm .0448$
$r_{5g} = .1122 \pm .0444$
$r_{6g} = .1000 \pm .0446$

The correlations of the vocabulary, arithmetic reasoning, and Minnesota tests with what is common to each of these tests and the three memory tests are all low and insignificant, being well within 4 $P.E._r$. These results definitely establish the independence of the central memory factor found. On examining the tetrad differences, however, a situation which at first may seem puzzling is encountered, since the tetrad criterion is satisfied in every case. This brings up an interesting theoretical point regarding the interpretation of the tetrad criterion. The tetrad difference criterion indicates that: if the tetrad differences from a given set of four variables are equal to zero (within P.E.$_t$), then the interrelationships of these four variables may be explained on the basis of a general and specific factors, without recourse to smaller group factors. However, the satisfaction of this criterion does not tell us whether or not the "general" factor necessarily runs through all four variables; it simply shows that we need assume no more than one common factor in addition to the specifics. This necessary restriction in the interpretation of the tetrad criterion is brought out very nicely in the fact that the criterion will be satisfied in a situation in which there is a common factor running through three tests, but not through the fourth. This can be demonstrated very readily:

Let 1, 2 and 3 be variables made up of a central factor and specific factors, all the correlations between them being due entirely to the central factor. Let 4 be a variable having no common factors with any of the variables 1, 2 or 3, its correlations with these variables being zero (within P.E.$_r$).

The intercorrelations will then be:

$$\begin{array}{ll} r_{12} = m & r_{23} = p \\ r_{13} = n & r_{24} = 0 \\ r_{14} = 0 & r_{34} = 0 \end{array}$$

in which m, n, and p are any correlation coefficients greater than zero.

The tetrads will be:

$$\begin{aligned} t_{1234} &= r_{12}\ r_{34} - r_{13}\ r_{24} = m \times 0 - n \times 0 = 0 \\ t_{1243} &= r_{12}\ r_{34} - r_{14}\ r_{23} = m \times 0 - 0 \times p = 0 \\ t_{1342} &= r_{13}\ r_{24} - r_{14}\ r_{23} = n \times 0 - 0 \times p = 0 \end{aligned}$$

This is exactly the situation we have when we combine the three memory tests with one of our non-memory tests in the tetrads reported in Table X. If, however, we compute r_{ag} for variable 4 in our hypothetical problem, it will in each case be zero, indicating the absence of the general factor in this variable:

$$r_{4g} = \sqrt{\frac{r_{14}\ r_{24}}{r_{12}}} = \sqrt{\frac{0 \times 0}{m}} = 0$$

$$r_{4g} = \sqrt{\frac{r_{14}\ r_{34}}{r_{13}}} = \sqrt{\frac{0 \times 0}{n}} = 0$$

$$r_{4g} = \sqrt{\frac{r_{24}\ r_{34}}{r_{23}}} = \sqrt{\frac{0 \times 0}{p}} = 0$$

The upshot of this discussion seems to be that the *ultimate* criterion of the presence of a general factor through a given set of variables is not the tetrad equation but the correlation of each variable with the central factor; if r_{ag} for any of the variables is less than four times its P.E., then we cannot assume the presence of the general factor in this variable, even though every tetrad difference computed with it may be zero.[14]

VII. Regression Equation and Multiple Correlations With Central Factor

The multiple regression equation for estimating the central memory factor was computed, using the four test combinations finally selected. The variables in the equation are:

x_0 = central memory factor
x_1 = word-word
x_2 = picture-number + form-number
x_3 = color-word + retained members
x_4 = syllable recognition

The regression equation was computed in terms of reduced scores, each score, including the criterion score, being expressed as a deviation from the mean of its distribution divided by the standard deviation of that distribution. In this form, the regression equation gives the relative weights with which each independent variable enters into the dependent variable (x_0). The values obtained for the regression coefficients are as follows:

$$x_0 = .2020x_1 + .4433x_2 + .3752x_3 + .1032x_4$$

The multiple correlations of successive combinations of the four tests with x_0, the central memory factor, were also computed. These correlations are as follows:

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[14] The tetrad differences should be computed as a preliminary step in order to determine whether there are any group factors through the variables, since the r_{ag} formula should not be applied when such factors are present.

$r_{01} = .6623$
$R_{0(12)} = .8287$
$R_{0(123)} = .8889$
$R_{0(1234)} = .8938$

The last multiple correlation ($R_{0(1234)}$) gives the correlation of the entire battery of tests (each test given its optimum weight) with the central memory factor. This correlation, being nearly .90, indicates that the memory factor is measured quite completely by the present battery of tests.

VIII. Coefficients of Total and Net Determination[15]

The coefficient of "total determination" gives the per cent of the total variance[16] of the dependent variable (x_0) which is attributable to the variance of all the independent variables taken together, *i.e.*, the variance of the entire battery of tests. The coefficient of total determination can then be broken down into coefficients of "net determination," showing the per cent of the variance of the dependent variable attributable to each of the independent variables. The coefficients of total and net determination have been computed for the present data from the regression coefficients given above. The coefficient of total determination, or $\frac{\sigma_{0c}}{\sigma^2_0}$, is equal to $R^2_{0(1234)}$, being simply the square of the multiple correlation. This can be broken down into coefficients of net determination as follows:

$$R^2_{0(1234)} = \frac{b_{01.234}\ p_{01}}{\sigma^2_0} + \frac{b_{02.134}\ p_{02}}{\sigma^2_0} + \frac{b_{03.124}\ p_{03}}{\sigma^2_0} + \frac{b_{04.123}\ p_{04}}{\sigma^2_0}$$

in which $b_{01.234}$, $b_{02.134}$, etc., are the regression coefficients, and p_{01}, p_{02}, etc., are the product moments.

The above formulas have been taken from Watkins (44). They have been modified for use in the present study as follows:

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[15] Watkins (44).
[16] "Variance" = (S.D.)^2.

Since, $p_{01} = \frac{\Sigma x_0 x_1}{N}$, and $r_{01} = \frac{\Sigma x_0 x_1}{N \sigma_0 \sigma_1}$, we may write,

$$p_{01} = r_{01} \ \sigma_0 \ \sigma_1$$

The coefficients of net determination may then be written in the form of:

$$\frac{b_{01.234} \ r_{01} \ \sigma_0 \ \sigma_1}{\sigma^2_0}, \text{ or } \frac{b_{01.234} \ r_{01} \ \sigma_1}{\sigma_0}$$

Since we are dealing with reduced scores throughout, all the σ's are equal to 1.00 and may therefore be omitted from the formulas. The equation in its final form then becomes:

$$R^2_{0(1234)} = b_{01.234} \ r_{01} + b_{02.134} \ r_{02} + b_{03.124} \ r_{03} + b_{04.123} \ r_{04}$$

Substituting the appropriate numerical values in this equation, we get:

$$79.89\% \ x_0 = 13.37\% \ x_1 + 34.22\% \ x_2 + 27.59\% \ x_3 + 4.70\% \ x_4.$$

This means that 13.37% of the total variance of the central memory factor is attributable to test 1 (word-word), 34.22% to test 2 (picture-number + form-number), 27.59% to test 3 (color-word + retained members), and 4.70% to test 4 (syllable recognition), the total battery accounting for 79.89% of the variance of the central factor.

IX. Size of the Memory Factor in Our Tests

Our next problem was to find the degree to which a subject's capacity in the central memory factor determines his performance on each of our memory tests. It can be shown that the per cent of the variance in a test due to the central factor is simply the square of the correlation of that test with the central factor. Let x_1 represent a single individual's score in test 1, expressed as a deviation from the mean of the distribution. Let x_2 represent the same individual's score in test 2, similarly expressed. Then we may write:

[1.] $x_1 = c_1 g + s_1$ (in which c_1 and c_2 are constants,
[2.] $x_2 = c_2 g + s_2$ g the central factor, and s_1 and s_2 specific factors).

Multiplying equations 1 and 2,

$$x_1 x_2 = c_1 c_2 g^2 + c_2 g s_1 + c_1 g s_2 + s_1 s_2$$

Summing and dividing by N,

$$\frac{\Sigma x_1 x_2}{N} = c_1 c_2 \frac{\Sigma g^2}{N} + c_2 \frac{\Sigma g s_1}{N} + c_1 \frac{\Sigma g s_2}{N} + \frac{\Sigma s_1 s_2}{N}$$

Since the specific factors are by definition uncorrelated with each other and with g, the last three terms of the equation drop out, being equal to zero. The equation then becomes,

$$r_{12}\sigma_1\sigma_2 = c_1c_2\sigma^2_g$$

$$[3.] \qquad r_{12} = \frac{c_1c_2\sigma^2_g}{\sigma_1\sigma_2}$$

Let $a_1 = \frac{c_1\sigma_g}{\sigma_1}$ and $a_2 = \frac{c_2\sigma_g}{\sigma_2}$

We may then write, from equation 3

$$\begin{array}{ll} r_{12} = a_1a_2 & r_{23} = a_2a_3 \\ r_{13} = a_1a_3 & r_{24} = a_2a_4 \\ r_{14} = a_1a_4 & r_{34} = a_3a_4 \end{array}$$

Then $r_{1g} = \sqrt{\frac{r_{12}\ r_{13}}{r_{23}}} = \sqrt{\frac{a_1a_2\ a_1a_3}{a_2a_3}} = a_1$

Squaring equation [1] above, summing and dividing by N, we get, for the variance of test 1,

$$\sigma^2_1 = c^2_1\ \sigma^2_g + \sigma^2_s$$

$$\text{or } 1 = \frac{c^2_1\ \sigma^2_g}{\sigma^2_1} + \frac{\sigma^2_{s1}}{\sigma^2_1}$$

$$\therefore 1 = a^2_1 + \frac{\sigma^2_{s1}}{\sigma^2_1}$$

$\therefore a^2_1 = (r_{1g})^2 =$ variance in test 1 due to g.

Applying this to our own data, we find that the variance in each of our four memory tests due to the central memory factor is:

Test 1	43.86%
Test 2	59.60%
Test 3	54.10%
Test 4	20.79%
Total Battery	79.89%

X. Comparative Evaluation

As we have already stated in Chapter I, the present problem represents only one phase of the more general problem of mental trait organization. It seems fitting, therefore, now that our own specific results have been reported and interpreted, to present these results in their broader setting and compare them with the results obtained on other group factors by similar techniques. The results obtained by Schneck (34) are comparable to our results both with respect to group of subjects used and with respect to general statistical techniques. We have, therefore, compared our results on the memory factor with Schneck's results on the verbal and number factors with respect to a number of values. In Tables XI, XII, XIII, and XIV are presented, for each of the three factors, correlations of tests with central factors, intercorrelations of tests with central factor partialed out, coefficients of total and net determination, and per cent of variance in each test due to the central factor. Only the first of these values, *viz.,* correlation of tests with central factor, is given by Schneck for his data; the other values have been computed by the present writer, the quantities required in these computations being available in Schneck (34). The variables taken from Schneck are:

Verbal Ability	*Number Ability*
1—Vocabulary	1—Arithmetic Reasoning
2—Analogies	2—Number Series Completion
3—Sentence Completion	3—Equation Relations
4—Disarranged Sentences	4—Multiplication

Our results on the memory factor are very similar to Schneck's results on the verbal and number factors. The correlation of our total memory battery with the central memory factor is slightly lower than the corresponding correlation of Schneck's verbal battery, but higher than the correlation of his number battery. The correlations of our individual memory tests with the central factor are higher than his correlations with the number factor, and, although our two best tests of memory do not correlate as highly with their central factor as his two best verbal tests, our two poorest memory tests correlate higher than the two poorest verbal tests. In other words, our memory tests are more uniform in the degree to which they measure the central factor than are Schneck's verbal tests.

The intercorrelations of the tests with the central factor partialed out are fairly uniform in the three factors in question, none of them being very significantly greater than zero.

TABLE XI

CORRELATION OF EACH TEST WITH CENTRAL FACTOR

Test	*Memory*	*Verbal*	*Number*
1.	.6623	.8695	.7666
2.	.7720	.8160	.5593
3.	.7355	.6081	.4613
4.	.4560	.3841	.4867
Total Battery	.8938	.9306	.8294

TABLE XII

INTERCORRELATIONS OF TESTS WITH CENTRAL FACTOR PARTIALED OUT

Correlations	*Memory*	*Verbal*	*Number*
$r_{12.g}$	.0277 ± .0450	—.1706 ± .0452	.0430 ± .0465
$r_{13.g}$	.0948 ± .0446	—.0256 ± .0465	.0383 ± .0465
$r_{14.g}$	—.0640 ± .0448	—.0362 ± .0465	—.0005 ± .0465
$r_{23.g}$	—.1863 ± .0434	—.1015 ± .0461	—.0084 ± .0465
$r_{24.g}$	.0613 ± .0448	—.0519 ± .0464	.0498 ± .0464
$r_{34.g}$	.0141 ± .0450	.0323 ± .0465	.0590 ± .0464

TABLE XIII

COEFFICIENTS OF TOTAL AND NET DETERMINATION

Coefficient	*Memory*	*Verbal*	*Number*
Total	79.89	86.60	68.79
Net 1.	13.37	51.87	28.15
Net 2.	34.22	23.76	15.98
Net 3.	27.59	8.15	9.74
Net 4.	4.70	2.78	8.56

TABLE XIV

PER CENT OF VARIANCE IN EACH TEST DUE TO CENTRAL FACTOR

Test	*Memory*	*Verbal*	*Number*
1.	43.86	80.37	58.77
2.	59.60	66.59	31.28
3.	54.10	36.98	21.28
4.	20.79	14.75	23.69
Total Battery	79.89	86.60	68.79

The coefficients of total and net determination, as well as the variance in each test due to the central factor substantiate the conclusions stated above, *viz.*, that (1) the memory battery is a somewhat better measure of its central factor than the number battery, and somewhat poorer than the verbal battery; (2) the individual memory tests cover a larger proportion of their central factor than the individual number tests; and (3) the individual memory tests are more uniform in the amount of central factor they cover than the individual verbal tests.

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CHAPTER V

SUMMARY

1. A group of 225 subjects, chosen because of their homogeneity with respect to age, racial descent, educational and social status, etc., were given 8 tests of immediate memory for visually presented material and 3 non-memory tests.

2. Evidence of the presence of a central factor through the memory tests was found in (1) the size of the average intercorrelation of the memory tests; (2) the results of the application of the tetrad criterion; and (3) the correlations of each test with the central factor. The last criterion (r_{ag}) is shown to be the most crucial on theoretical grounds.

3. The independence of the central factor in our memory tests was shown by the correlations of the non-memory tests with the central memory factor, all of which were smaller than 4 $P.E._{r}$.

4. A multiple regression equation for estimating scores in the central memory factor from our battery of memory tests is given.

5. Coefficients of total and net determination showing the per cent of the variance of our central memory factor attributable to the entire battery and to each of our tests, are given. The per cent of the variance of each of our tests due to the central memory factor is also given.

6. A comparison of our data with those of Schneck (34) on the verbal and number factors shows considerable uniformity in the results of the two studies.

CHAPTER VI

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